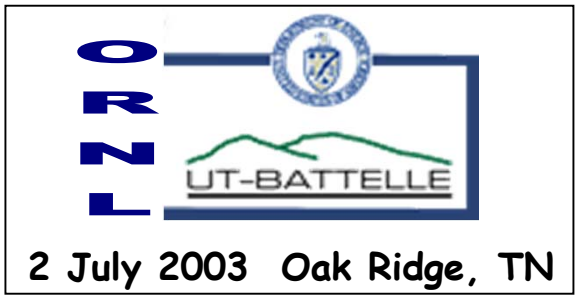

The SuperGrid: Combined Delivery and Storage of Electricity and Hydrogen

P. M. Grant, (Electric Power Research Institute)
pgrant@epri.com

ftp://grant:marulo@ftp.epri.com/Nat%20Lab%20SuperGrid%20Proposal/

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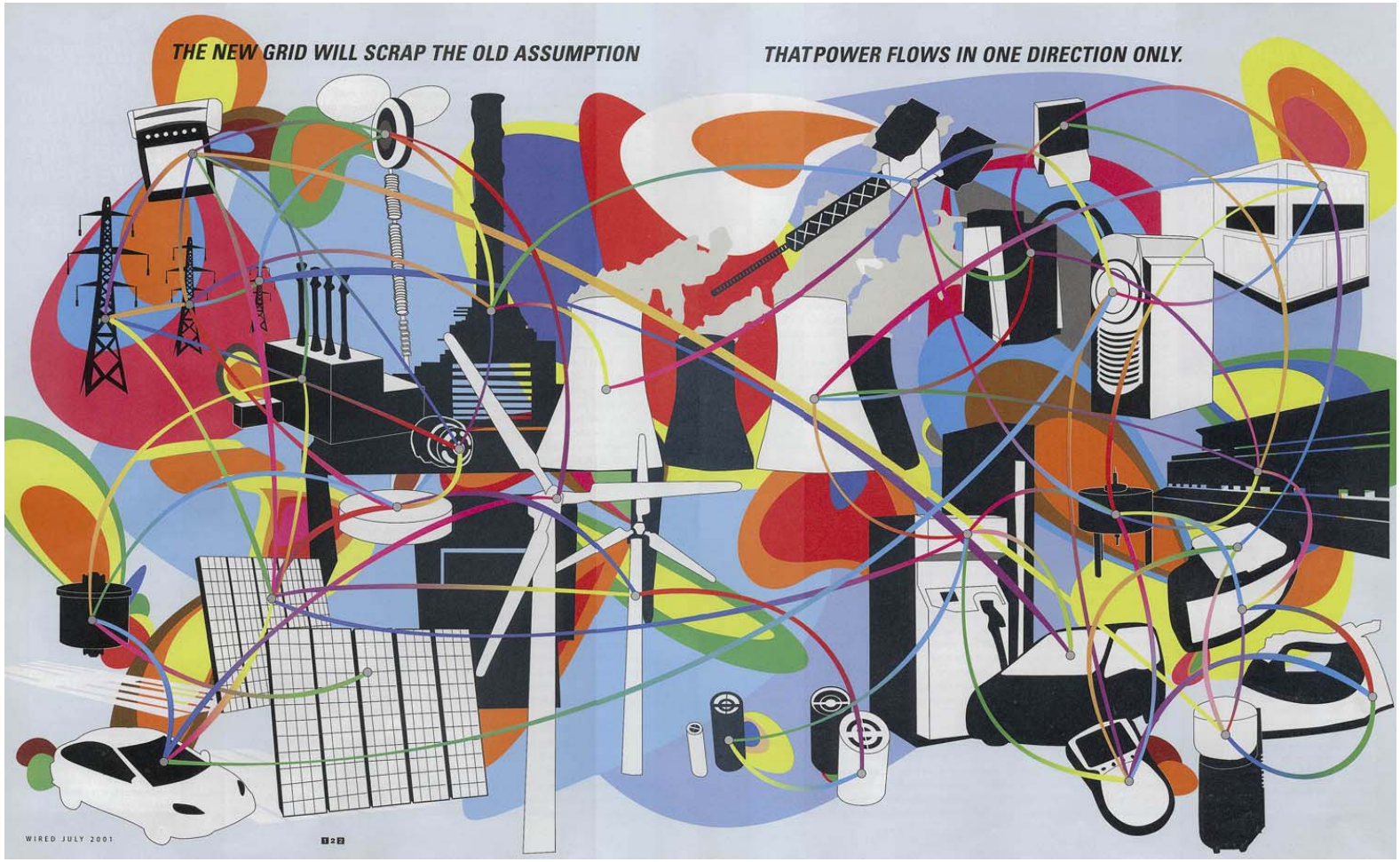
"The Challenge"



Wired Magazine, June 2001

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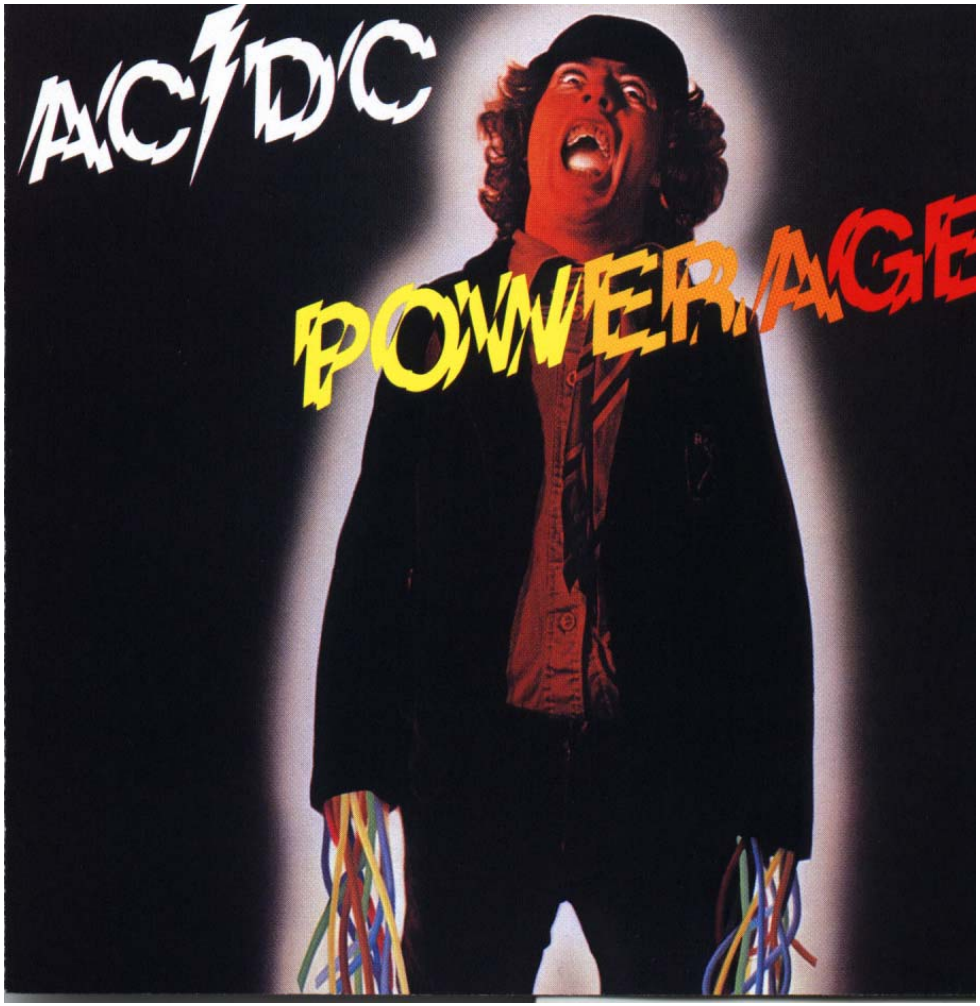
Californication!



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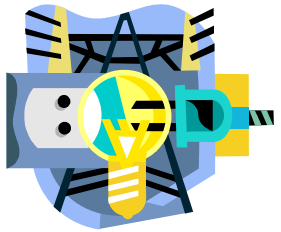
Architecture

Three Dimensions

- ***SuperGrid*** **– A superconducting, H_2-cooled interstate "backbone" connecting regions coast to coast.**

- ***RegionGrid*** **– Two grid operators (East and West) with upgraded high capacity lines to transmit power regionally.**



- ***CityGrid*** **– Local mini- and micro-grids with distributed intelligence, energy resources, and demand response**

Integrated systems architecture enables *NationalGrid* operations across all dimensions.

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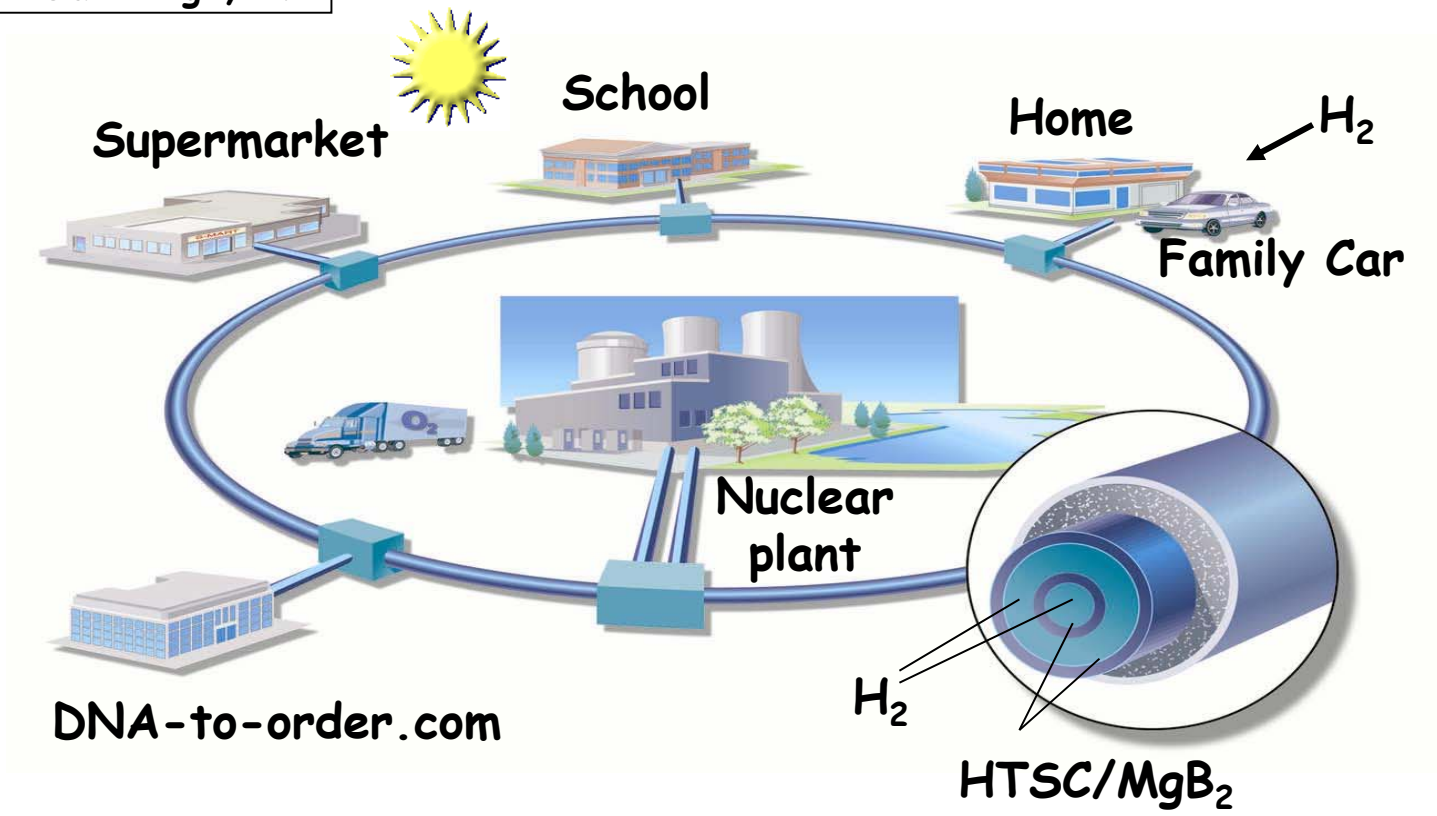
SuperCity



P.M. Grant, The Industrial Physicist, Feb/March Issue, 2002

ftp://grant:marulo@ftp.epri.com/Nat%20Lab%20SuperGrid%20Proposal

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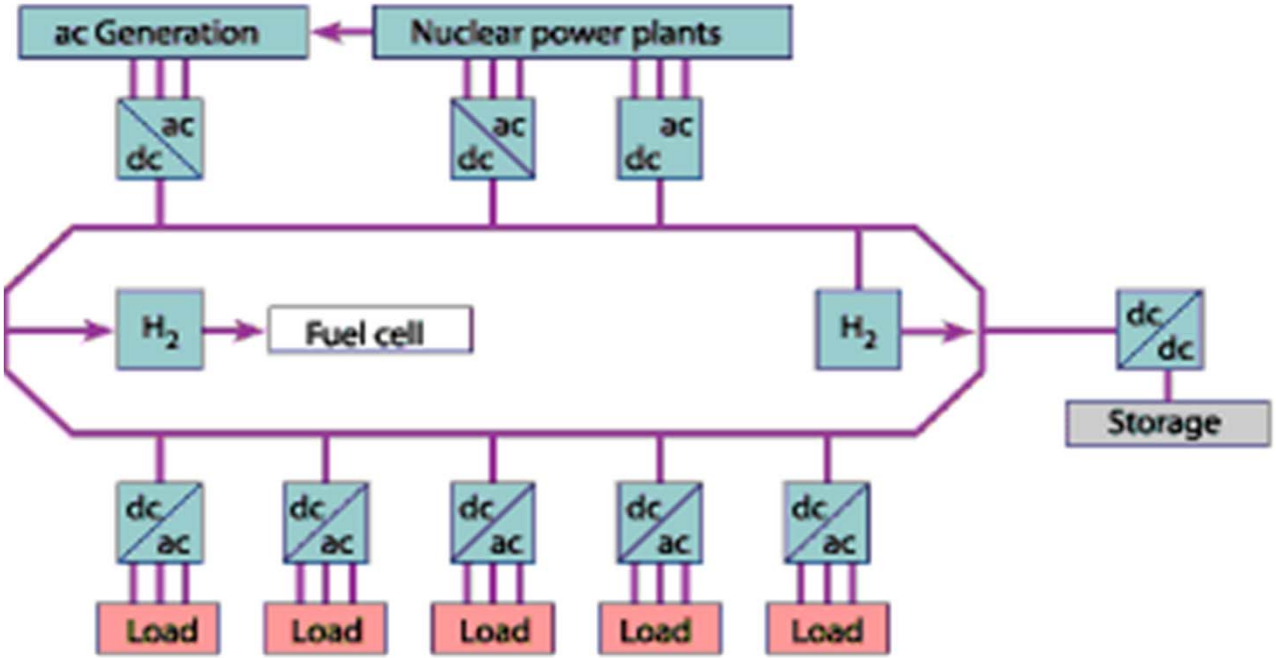
SuperGrid



Continental SuperGrid

"Continential SuperGrid Workshop," UIUC/Rockefeller U., Palo Alto, Nov. 2002

ftp://grant:marulo@ftp.epri.com/Energy%20SuperGrid%20Workshop%20Proceedings/

http://www.epri.com/journal/details.asp?doctype=features&id=511

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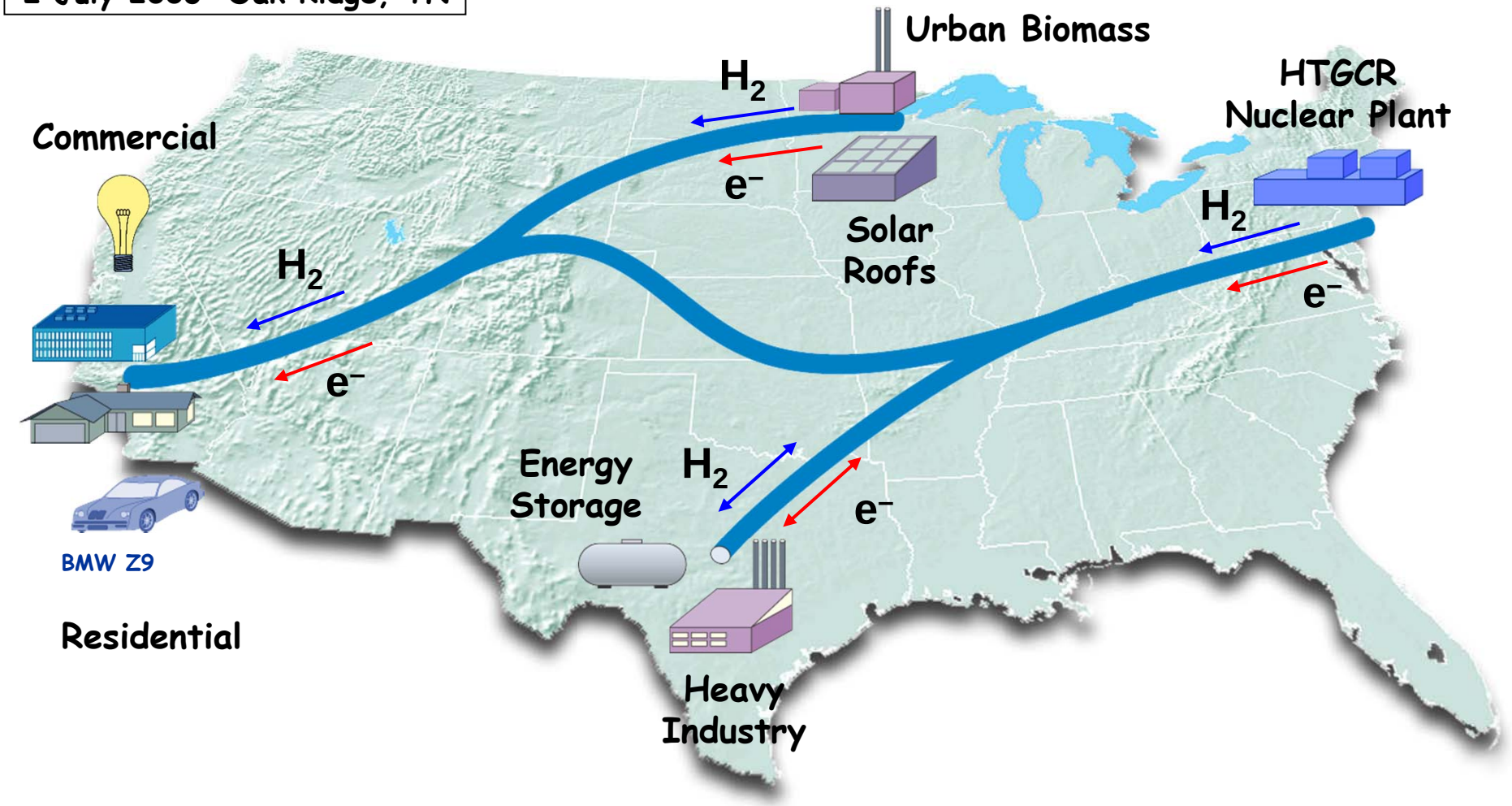
North American 21st Century Energy SuperGrid



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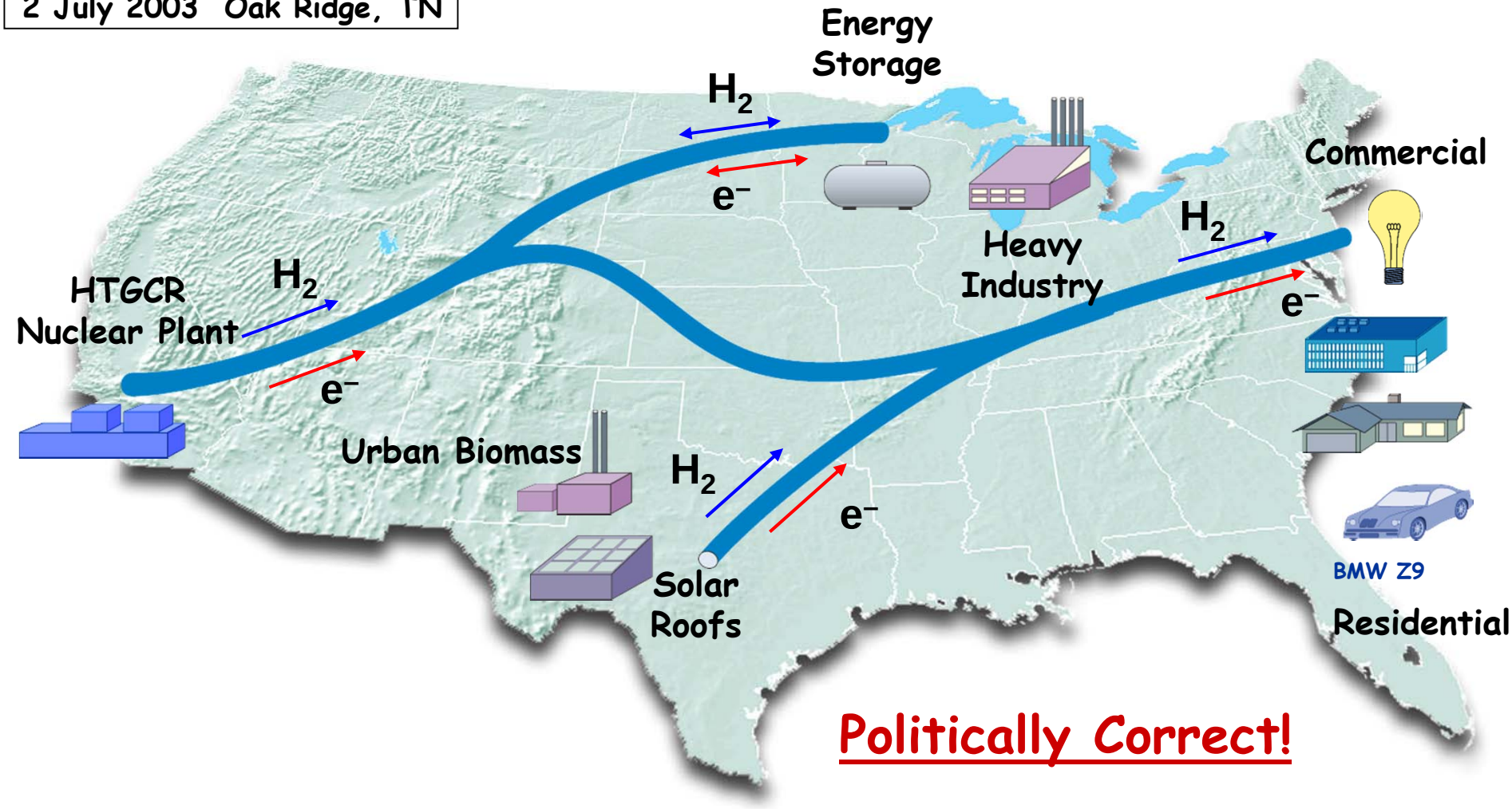
North American 21st Century Energy SuperGrid



Politically Correct!

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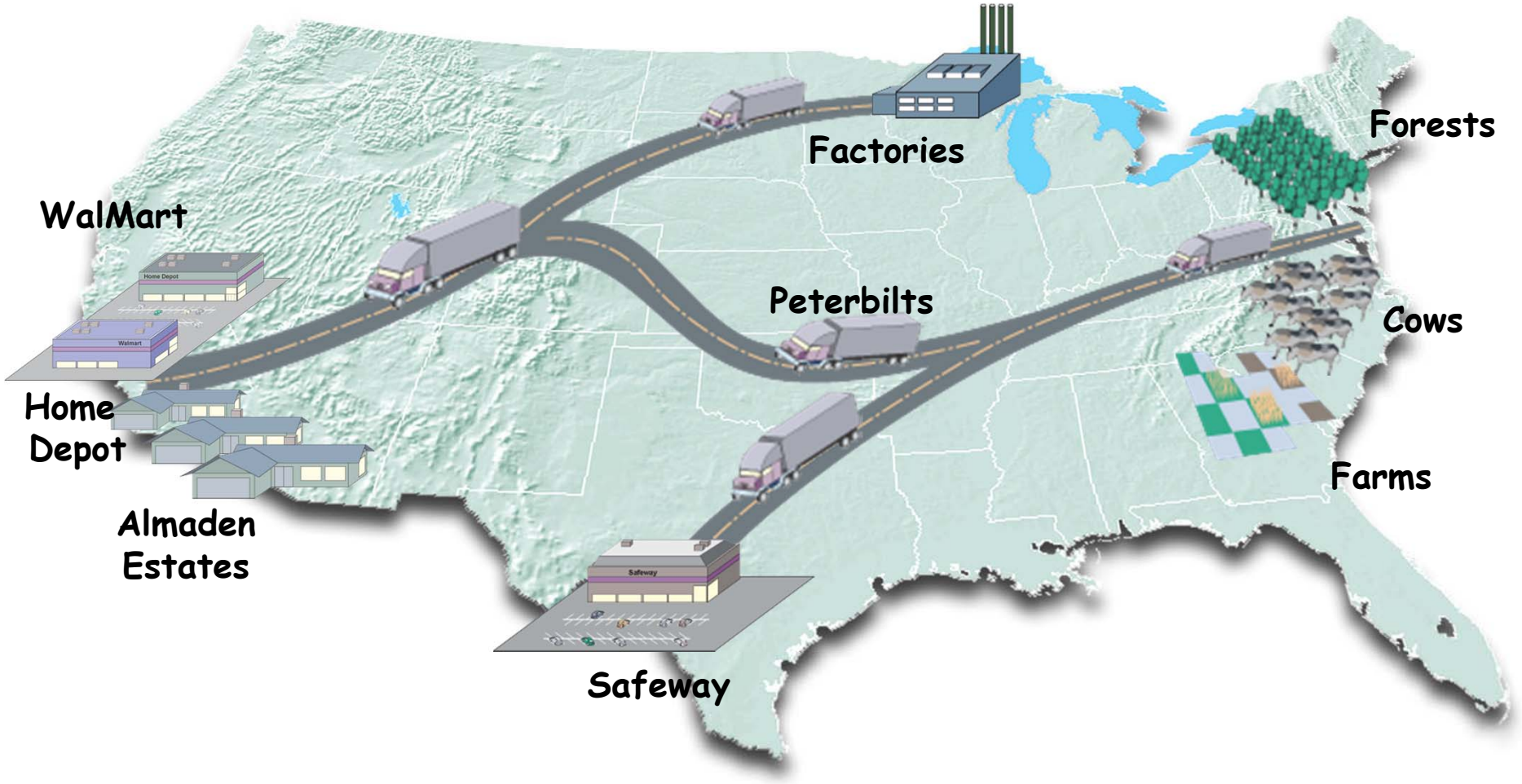
Interstate 80
The 20th Century Diesel Grid



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Garwin-Matisoo (IBM, 1967)

100 GW dc, 1000 km !

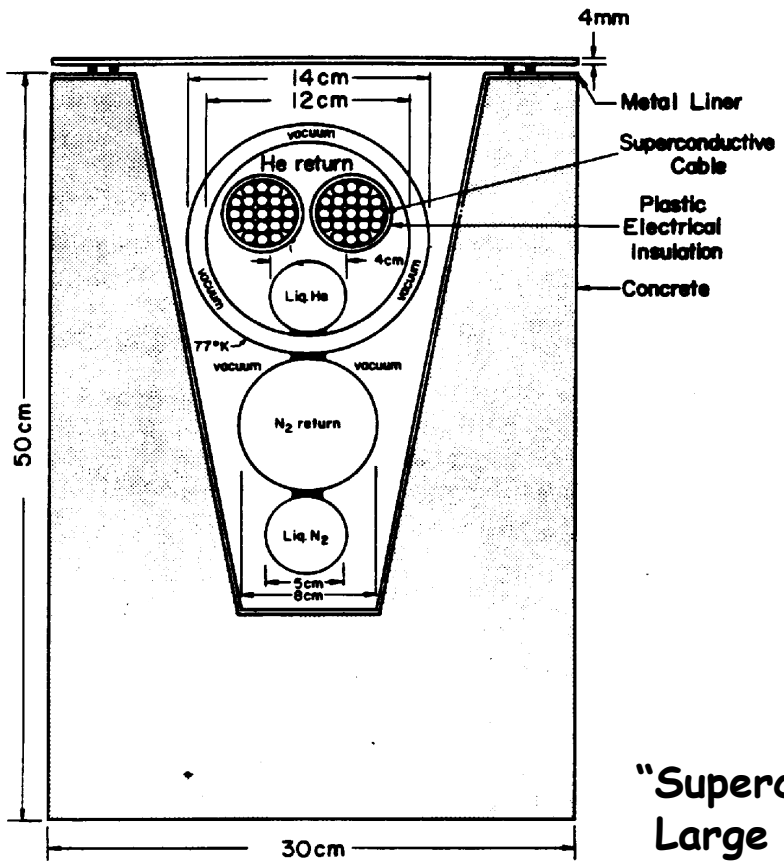

Fig. 1. Cross section of the 100-GW line.

- Nb_3Sn Wire
- T_c = 9 K
- LHe liquid-vapor cooled
- LN_2 heat shield

"Superconducting Lines for the Transmission of Large Amounts of Electric Power over Great Distances," R. L. Garwin and J. Matisoo, Proc. IEEE 55, 538 (1967)

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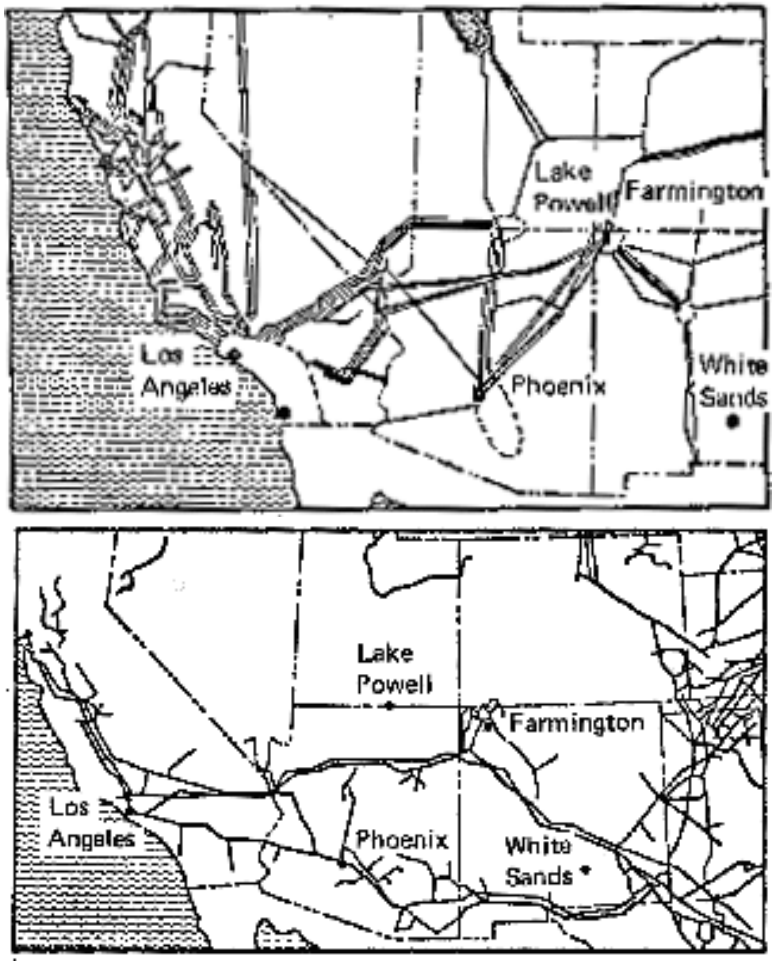
Electricity + Gas (LASL, 1972)

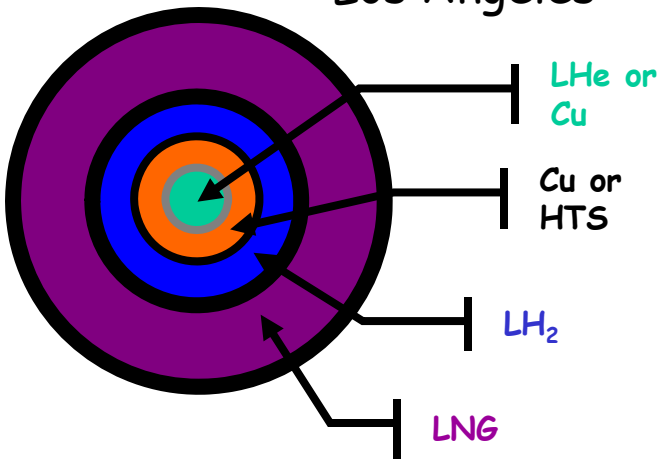
"Multiple Use of Cryogenic Fluid Transmission Lines."

J.R. Bartlit, F.J. Edeskuty, & E.F. Hammel, ICEC 4, 1972.



NM Space Shuttle Center

- Electricity
  - Four Corners
  - Lake Powell
- Natural Gas
  - Coal Gasification (NM)
- Hydrogen
  - Los Angeles



Cryogenic fluids served as heat shields for superconducting or cryoresistive conductor

EPRI

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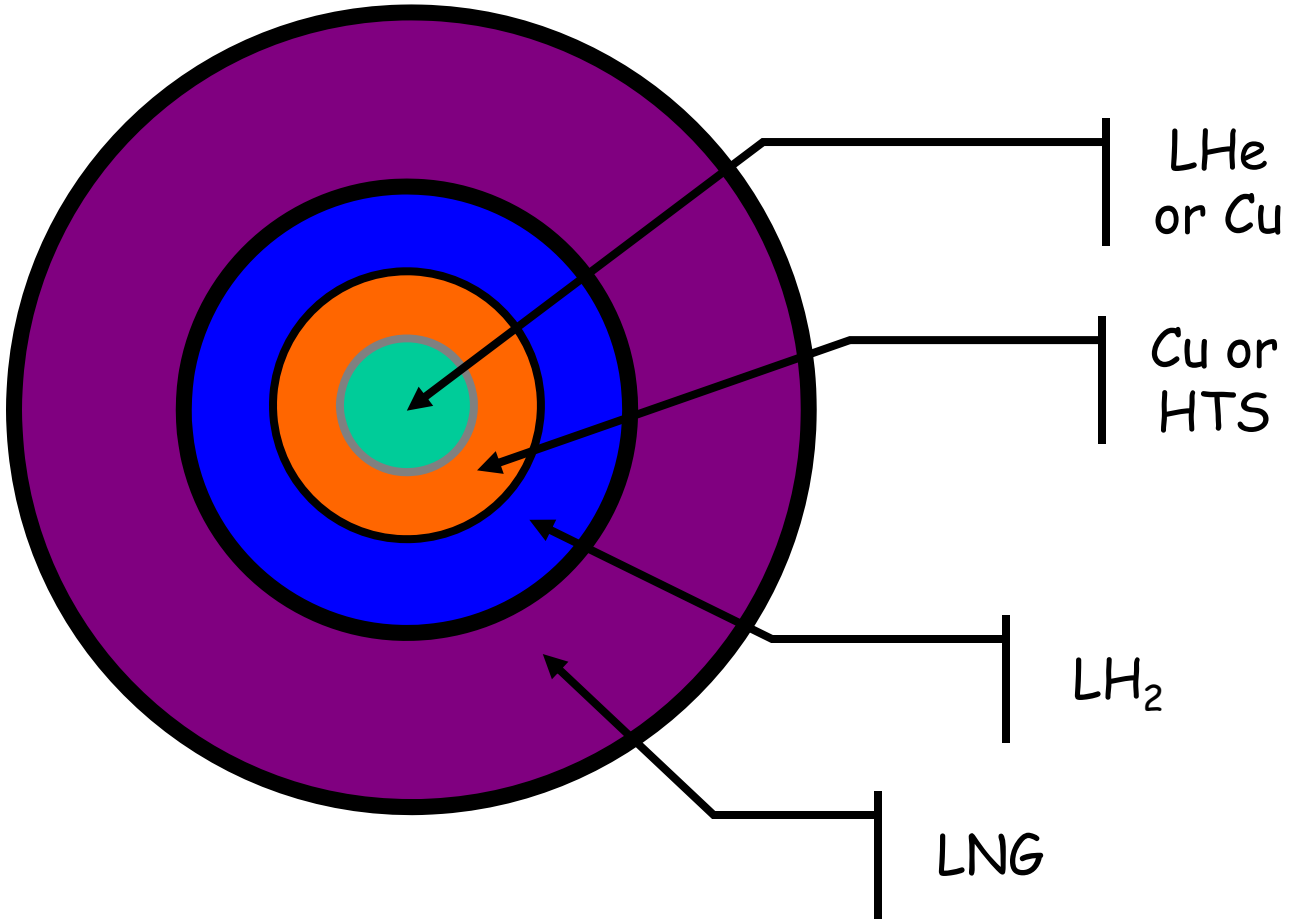
LASL Energy Delivery System



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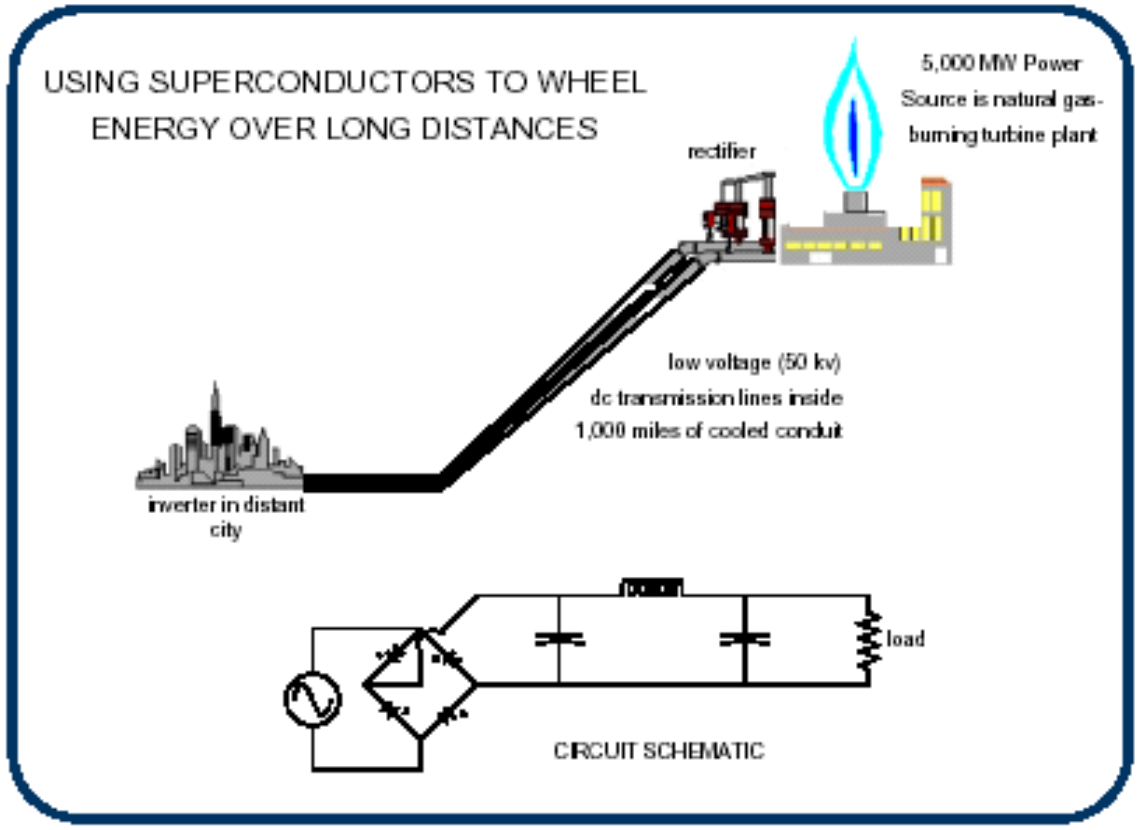
Electricity Pipe



Initial EPRI study on long distance (1000 km) HTSC dc cable cooled by liquid nitrogen

-- 1997 --

P.M. Grant, S. Schoenung, W. Hassenzahl, EPRI Report 8065-12, 1997

ftp://grant:marulo@ftp.epri.com/Nat%20Lab%20SuperGrid%20Proposal

EPRI

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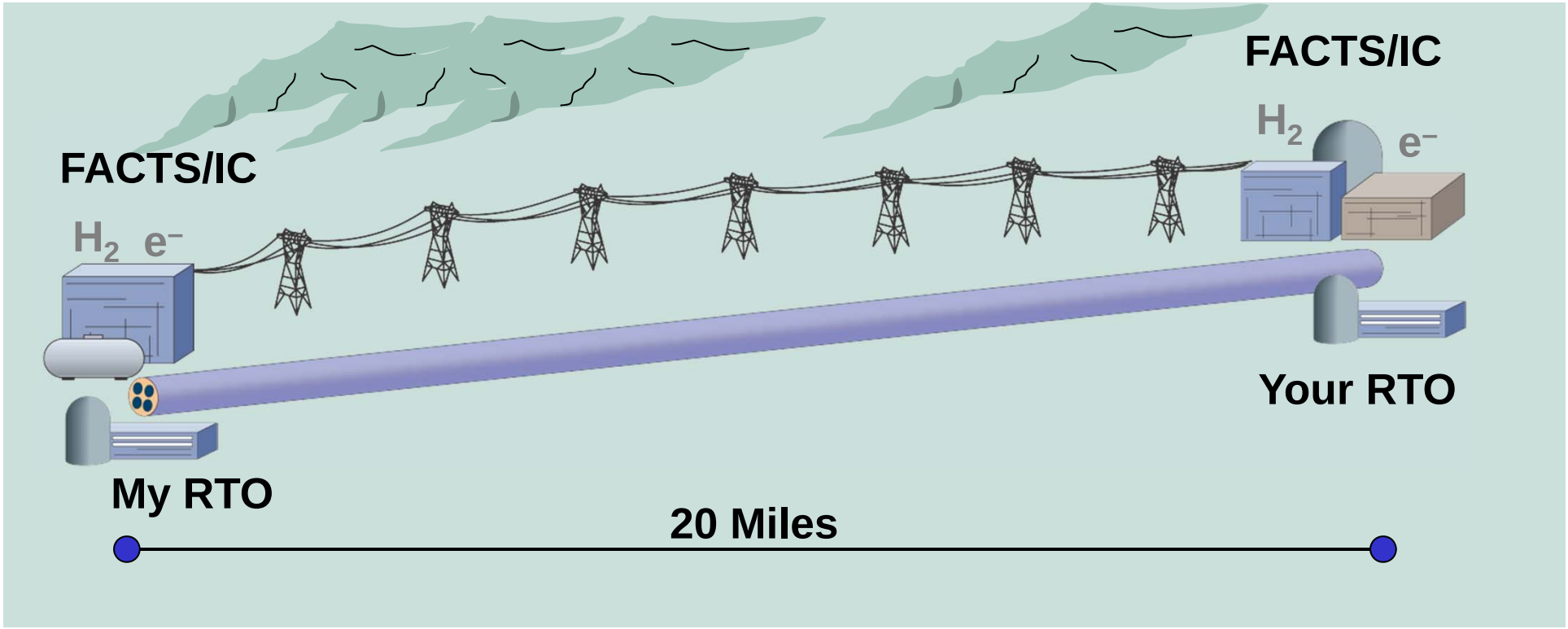
RegionGrid Interconnection



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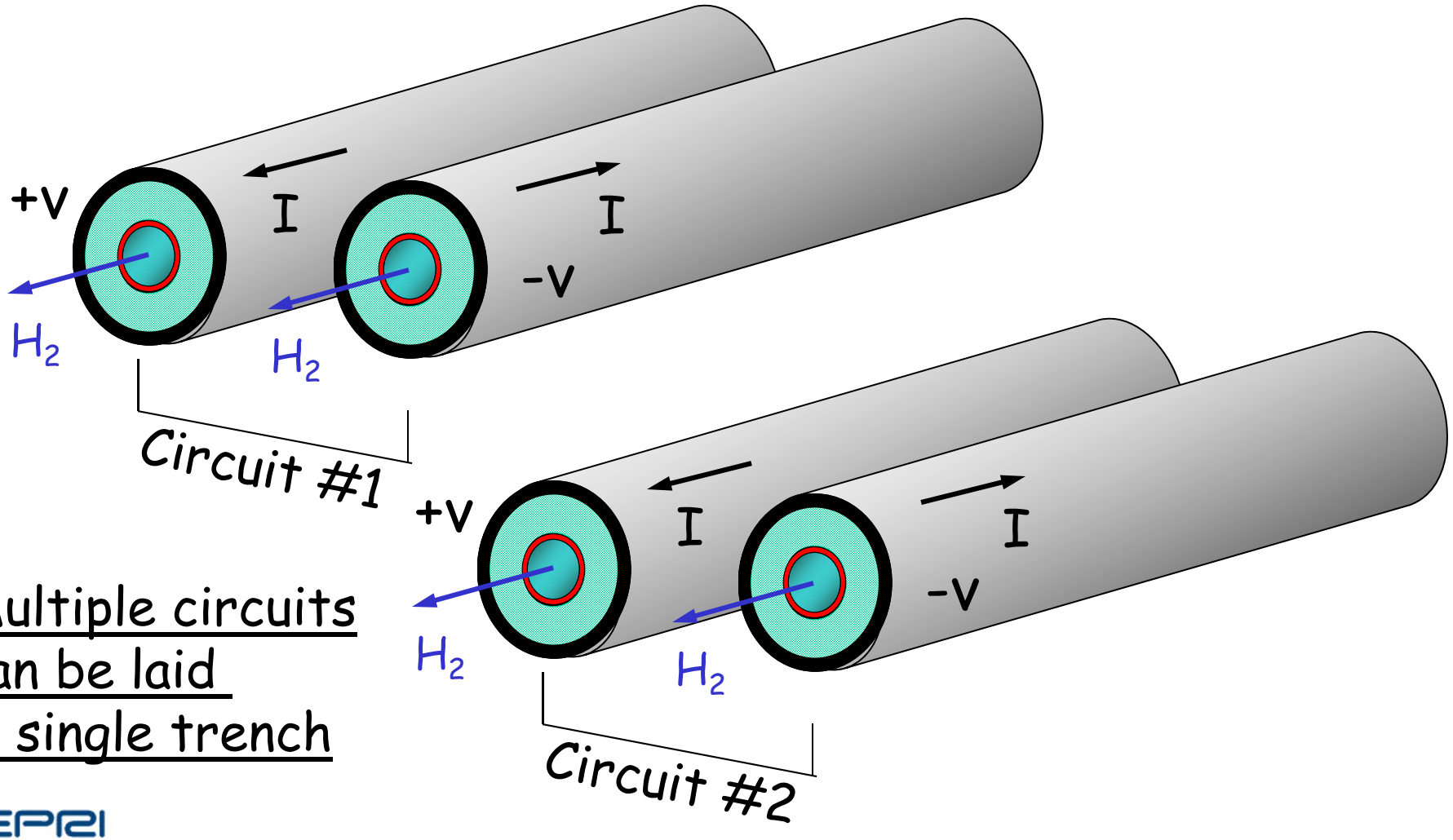
SuperCables



Multiple circuits can be laid in single trench

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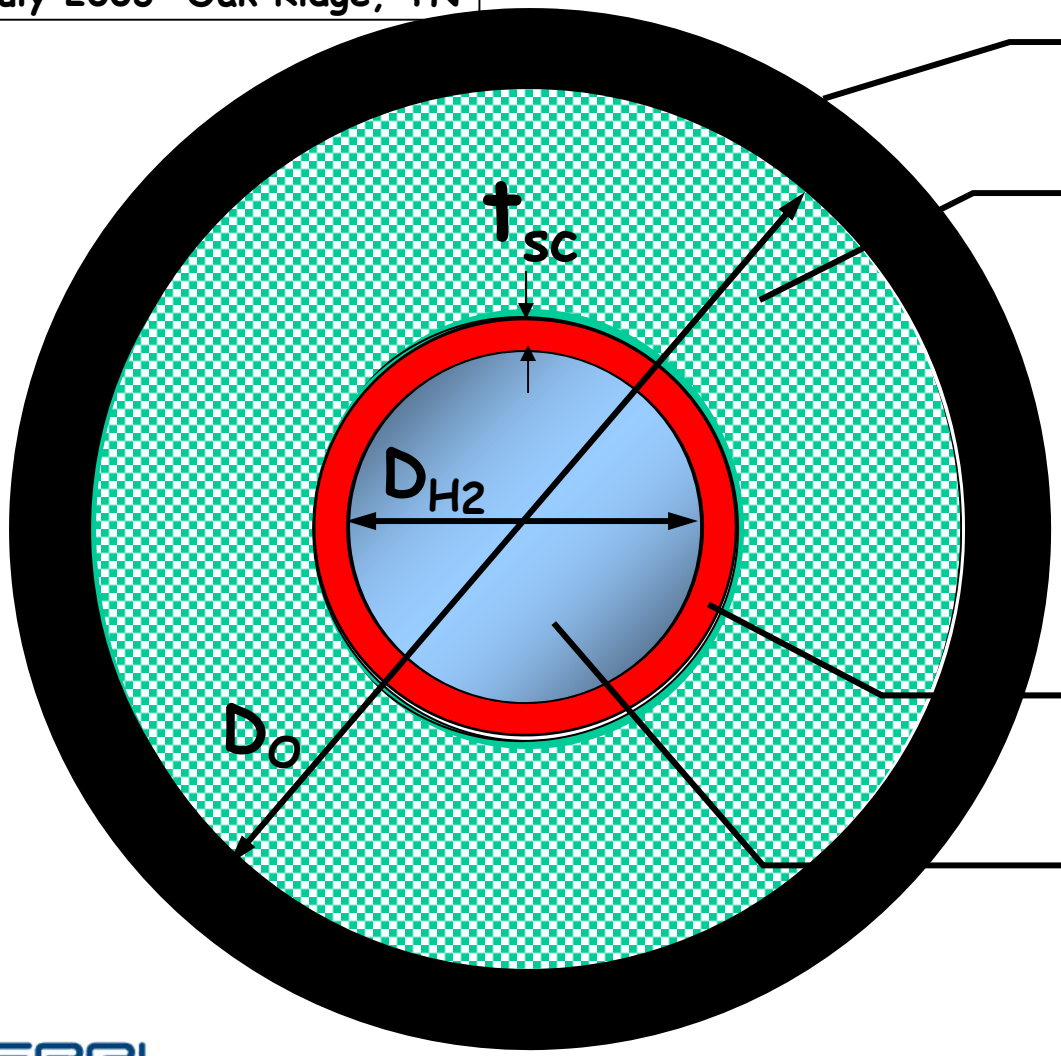
SuperCable



HV Insulation

"Super-Insulation"

Superconductor

Hydrogen

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Power Flows

Electricity

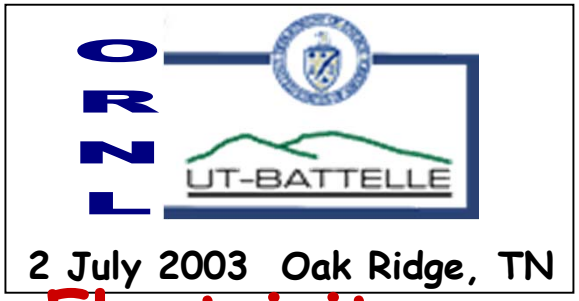
$P_{SC} = 2|V|IA_{SC}$, where

P_{SC} = Electric power flow
V = Voltage to neutral (ground)
I = Supercurrent
A_{SC} = Cross-sectional area of superconducting annulus

Hydrogen

$P_{H2} = 2(QpvA)_{H2}$, where

P_{H2} = Chemical power flow
Q = Gibbs H_2 oxidation energy (2.46 eV per mol H_2)
ρ = H_2 Density
v = H_2 Flow Rate
A = Cross-sectional area of H_2 cryotube



Electric & H_2 Power

Electricity

Power (MW)	Voltage (V)	Current (A)	Critical Current Density (A/cm^2)	Annular Wall Thickness (cm)
1000	+/- 5000	100,000	25,000	0.125

Hydrogen (LH_2, 20 K)

Power (MW)	Inner Pipe Diameter, D_{H2} (cm)	H_2 Flow Rate (m/sec)	"Equivalent" Current Density (A/cm^2)
500	10	3.81	318

Thermal Losses

Radiation Losses

$W_R = 0.5\varepsilon\sigma\,(T^4_{amb} - T^4_{SC})$, where

W_R = Power radiated in as watts/unit area
$\sigma = 5.67\times10^{-12}$ W/cm^{2}K^4
T_{amb} = 300 K
T_{SC} = 20 K
ε = 0.05 per inner and outer tube surface
D_{SC} = 10 cm

W_R = 3.6 W/m

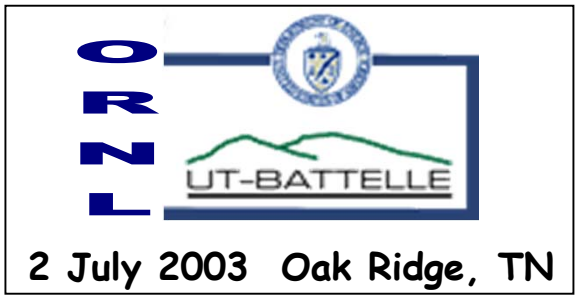
Superinsulation: $W_R^f = W_R/(n-1)$, where

n = number of layers

Target: W_R^f = 0.5 W/m requires ~10 layers

Other addenda (convection, conduction): W_A = 0.5 W/m

$W_T = W_R^f + W_A$ = 1.0 W/m

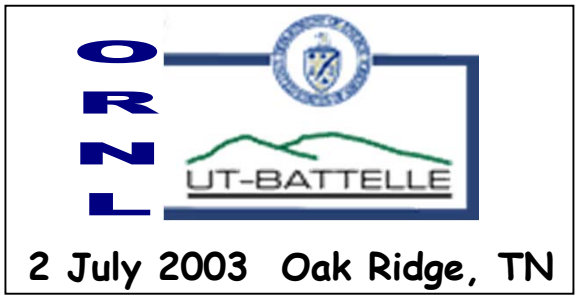


Heat Removal

$dT/dx = W_T/(\rho v C_P A)_{H2}$, where

dT/dx = Temp rise along cable, K/m
W_T = Thermal in-leak per unit Length
ρ = H_2 Density
v = H_2 Flow Rate
C_P = H_2 Heat Capacity
A = Cross-sectional area of H_2 cryotube

Take W_T = 1.0 W/m, then $dT/dx = 1.89 \times 10^{-5}$ K/m,
Or, 0.2 K over a 10 km distance



Remaining Issues

Current stabilization via voltage control

- AC interface (phases)
- Ripple suppression
- Charge/Discharge cycles

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Remaining Issues

Power Electronic Discretes

- GTOs vs IGBTs
- 12" wafer platforms
- Cryo-Bipolars
  - Minority carrier concentration
  - Doping profiles

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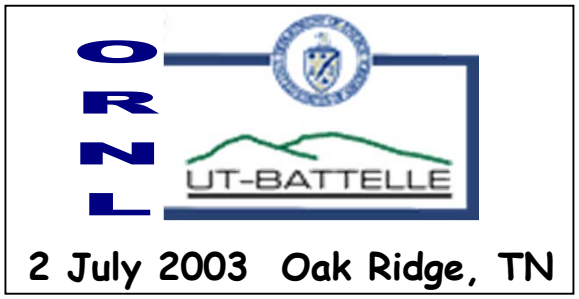
Remaining Issues

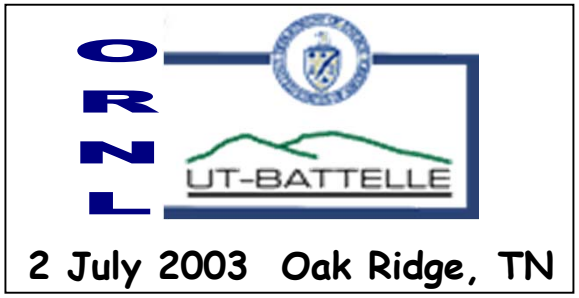
Hydrogen Issues

- Safety
- Generation (electrolysis)
- Cryocoolers
- Liquid vs Pressurized Gas
- Flow Rate
- Storage



Remaining Issues

Design & Prototyping!



S.14 Opportunity

- S.14 - Senate Energy Omnibus Bill
  - FY04 $15 M Authorization For OETD R&D
  - Section 927(e)(C):
    - *"Facilitate commercial transition toward direct current power transmission, storage, and use for high power systems utilizing high temperature superconductivity."*
- FY04 National Lab Study targeting prototype SuperCable by FY05 and beyond ($10 M ?)

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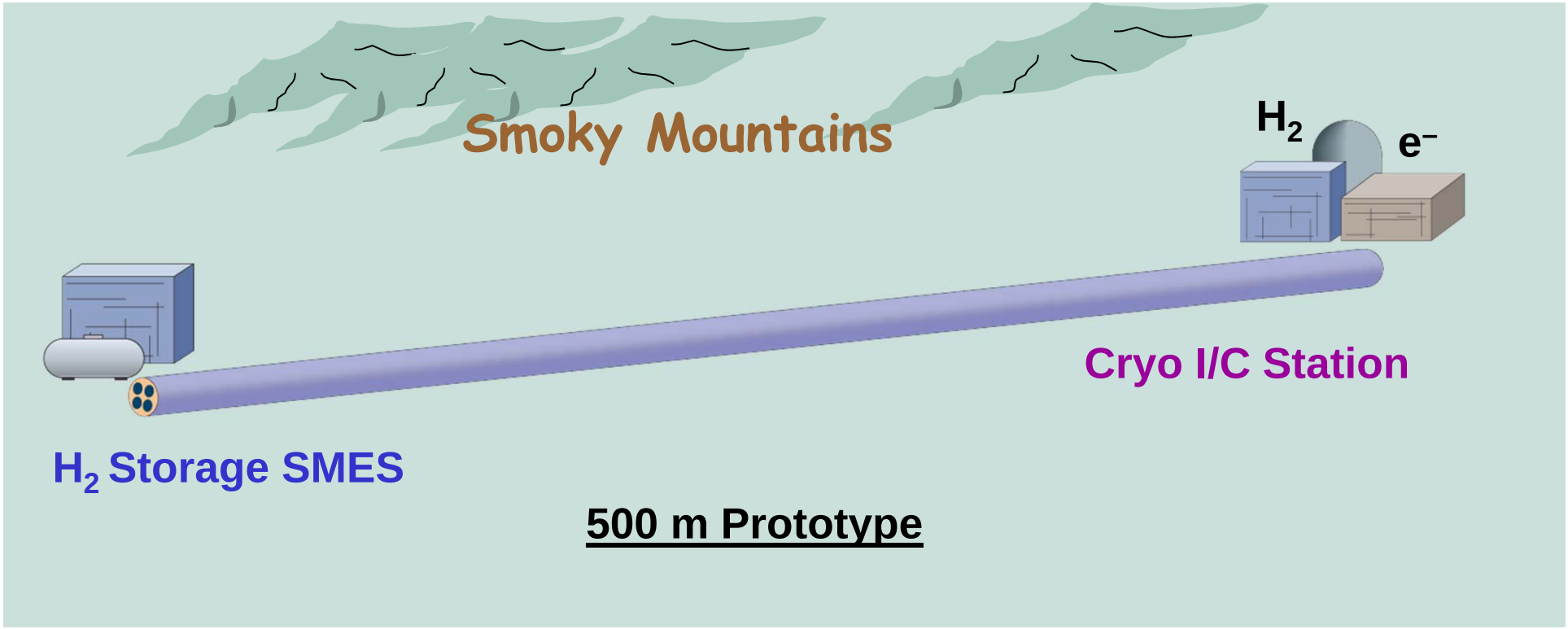
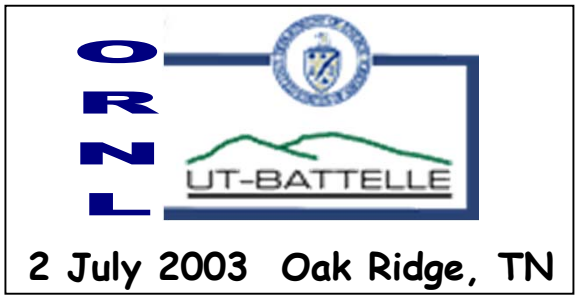
SuperCable Prototype Project



OAK RIDGE NATIONAL LABORATORY



Where there is no vision, the people perish…

Proverbs 29:18

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"You can't always get what you want..."

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"…you get what you need!"